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Environmental and economic effects of reducing pesticide use in agriculture*

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Abstract

Pesticides cause serious damage to agricultural and natural ecosystems. Thus, there is a need to curtail pesticide use and reduce the environmental impacts of pesticides. This study confirms that it should be possible to reduce pesticide use in the US by 50% without any decrease in crop yields or change in 'cosmetic standards'. The estimated increase in food costs would be only 0.6%. This increased cost, however, does not take into account the environmental and public benefits of reducing pesticide use by 50%.

Introduction

Several studies suggest that it is technologically feasible to reduce pesticide use in the US by 35–50% without reducing crop yields (Office of Technology Assessment (OTA), 1979; National Academy of Sciences, (NAS), 1989). Two recent events in Denmark and Sweden support these assessments. Denmark developed an action plan in 1985 to reduce pesticide use by 50% before 1997 (B.B. Mogensen, personal communication, 1989). Sweden also approved a program in 1988 to reduce pesticide use by 50% within 5 years (National Board of Agriculture, 1988). The Netherlands is developing a program to reduce pesticide use by 50% in 10 years (A. Pronk, personal communication, 1990). These proposals, along with the conclusion by Huffaker (1980) that the US overuses pesticides, prompted us to investigate the feasibility of reducing the annual use of synthetic organic pesticides by approximately one-half.

Farmers in the US use an estimated 320 million kg (700 million lb) of pesticides annually at an approximate cost of $4.1 billion (Table 1). Indeed, investment in pest control by pesticides has been shown to provide significant

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Table 1
US hectarage treated with pesticides (modified from Pimentel and Levitan, 1986)

Land-use category	Total hectares ($\times 10^6$)	All pesticides		Herbicides		Insecticides		Fungicides	
		Treated hectares ($\times 10^6$)	Quantity ($\times 10^6$ kg)	Treated hectares ($\times 10^6$)	Quantity ($\times 10^6$ kg)	Treated hectares ($\times 10^6$)	Quantity ($\times 10^6$ kg)	Treated hectares ($\times 10^6$)	Quantity ($\times 10^6$ kg)
Agricultural lands	472	114	320	86	220	22	62	4	38
Government and industrial lands	150	28	55	30	44	-	11	-	-
Forest lands	290	2	4	2	3	<1	1	-	-
Household lands	4	4	55	3	26	3	25	1	4
Total	916	148	434	121	293	26	99	5	42

Total for hectarage treated with herbicides, insecticides, and fungicides exceeds total treated hectares because the same land area can be treated with several classes of chemicals and several times.

economic benefits. Dollar returns for the direct benefits to farmers have been estimated to range from \$3 to \$5 for every \$1 invested in the use of pesticides (Headley, 1968; Pimentel et al., 1978). However, these figures do not reflect the indirect costs of pesticide chemical use such as human pesticide poisonings, reduction of fish and wildlife populations, livestock losses, destruction of susceptible crops and natural vegetation, honey-bee losses, destruction of natural enemies, evolved pesticide resistance, and creation of secondary pest problems (Pimentel et al., 1980). Moreover, these economic benefits are calculated based on current agricultural practices, some of which actually increase pest problems. Clearly, the direct and indirect benefits and costs of using pesticides in agriculture are highly complex.

The objective of this investigation is to estimate the potential agricultural and environmental benefits and costs of reducing pesticide use by approximately 50% in the US. To estimate the costs and benefits, this study (i) examines current pesticide use patterns in about 40 major US crops, (ii) evaluates current crop losses to pests, (iii) estimates the agricultural benefits and costs of reducing pesticide use by substituting currently available biological, cultural, and environmental pest control technologies for some current pesticide control practices, and (iv) assesses the public health and environmental costs associated with reduced pesticide use.

Extent of pesticide use

Of the estimated 434 million kg of pesticides used annually in the US, 67% are herbicides, 23% insecticides, and 10% fungicides (Table 1). The 320 million kg of pesticides used in agriculture are applied at an average rate of approximately 3 kg ha^{-1} to approximately 114 million ha, i.e. 62% of the 185 million ha that are planted (Pimentel and Levitan, 1986). Thus, a significant portion (38%) of crops receives no pesticides.

The application of pesticides for pest control is not evenly distributed among crops. For example, 93% of all row crops such as corn, cotton, and soybeans are treated with some type of pesticide (Pimentel and Levitan, 1986). In contrast, less than 10% of forage crops are treated. Herbicides are currently being used on approximately 90 million ha in the US, i.e. more than half of the nation's crop land, but nearly three-quarters of these herbicides are applied to just two major crops, corn and soybeans. Field corn alone accounts for 53% of agricultural herbicide use.

The situation is similar for insecticide use. Approximately 62 million kg of insecticides are applied to 5% of the total agricultural land (Table 1). Approximately 25% of all insecticides used are on cotton and corn. Fungicides are used primarily on fruit and vegetable crops (Pimentel and Levitan, 1986). Insecticide use also varies considerably among geographic regions. The warmer regions of the US often suffer more severe pest problems. For example, while only 13% of the alfalfa hectarage in the US is treated with insecticides, 89% of the alfalfa area in the Southern Plains states is treated to control insect pests (Eichers et al., 1978). In the mountain region, where large quantities of potatoes are grown, 65% of the potato crop land receives insecticide treatment, while in the southeast, where only early potatoes are grown, 100% of the potato crop land receives treatment with insecticides (US Department of Agriculture (USDA), 1975). Cotton insect pests such as the boll weevil are also a more serious problem in the southeast than in other regions (USDA, 1983). In the southeast and delta states, 84% of the cotton cropland receives treatment, whereas in the Southern Plains region less that half of the crop (40%) is treated. Moreover some crops (e.g. apples and cotton) can be treated as many as 20 times per season whereas other crops may be treated only once (e.g. corn and wheat).

Crop losses to pests and changes in agricultural technologies

Since 1945, the use of synthetic pesticides in the US has grown 33-fold (Fig. 1). The amounts of herbicides, insecticides, and fungicides used have changed with time mainly due to changes in agricultural practices and adoption of cosmetic standards (Pimentel et al., 1977). At the same time, the toxicity to pests and biological effectiveness of some of the pesticides used have increased at least ten-fold (Pimentel et al., 1991). For example, in 1945, DDT was applied at a rate of about 2 kg ha^{-1}. Today, effective insect control is achieved with pyrethroids and aldicarb applied at only 0.1 kg ha^{-1} and 0.05 kg ha^{-1}, respectively.

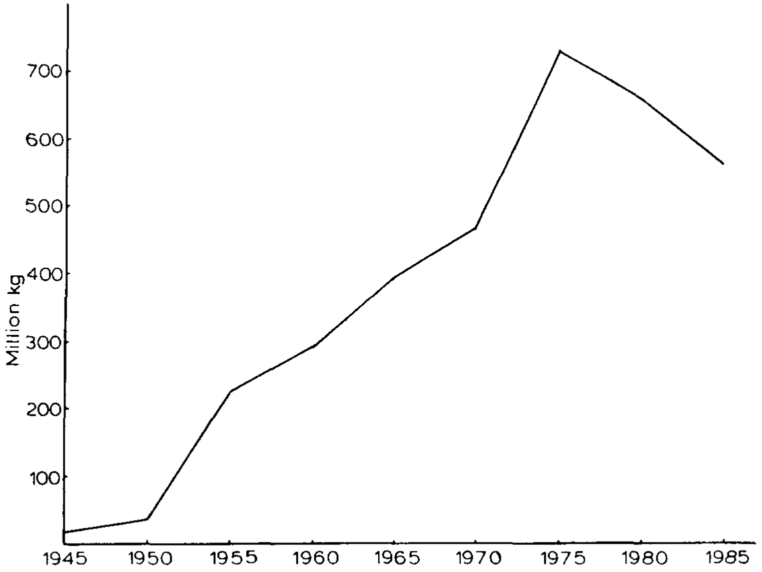

Fig. 1. The amounts of synthetic pesticides (insecticides, herbicides, and fungicides) produced in the US (Pimentel et al., 1991). Approximately 90% is sold in the US. The decline in total amount produced for use is in large part due to the ten- to 100-fold increased toxicity and effectiveness of the newer pesticides.

Currently, an estimated 37% of all crop production is lost annually to pests (13% to insects, 12% to plant pathogens, and 12% to weeds) in spite of the use of pesticides and non-chemical controls (Pimentel, 1986). Although pesticide use has increased during the past four decades, crop losses have not shown a concurrent decline. According to survey data collected from 1942 to the present, losses from weeds have fluctuated but declined slightly from 13.8% to 12% (Pimentel et al., 1991) (Table 2). This is due to improved chemical, mechanical, and cultural weed control practices. During that same period, US losses from plant pathogens, including nematodes, have increased slightly, from 10.5% to about 12% (Table 2). This results in part from reduced sanitation, higher cosmetic standards, and decreases in rotations.

The share of crop yields lost to insects has nearly doubled during the last 40 years (Table 2) despite more than a ten-fold increase in both the amount and toxicity of synthetic insecticide used (Pimentel et al., 1991). The increases in crop losses due to insects have been offset by increased crop yields obtained through the use of higher-yielding crop varieties and the greater use of fertilizers and other inputs (USDA, 1989).

This increase in crop losses despite increased insecticide use is due to several major changes that have taken place in agricultural practices. These include the planting of some crop varieties that are more susceptible to insect pests, the destruction of natural enemies of certain pests (which creates the

Table 2
Comparison of annual pest losses (dollars[a]) in the USA for the periods 1904, 1910–1935, 1942–1951, 1951–1960, 1974, 1989 (after Pimentel et al., 1991)

Period	Percentage of pest losses in crops				Crop value ($\$\times 10^9$)
	Insects	Diseases	Weeds	Total	
1989	13.0	12.0	12.0	37	150
1974	13.0	12.0	8.0	33.0	77
1951–1960	12.9	12.2	8.5	33.6	30
1942–1951	7.1	10.5	13.8	31.4	27
1910–1935	10.5	NA[b]	NA	NA	6
1904	9.8	NA	NA	NA	4

[a] Not adjusted.
[b] Not available.

need for additional pesticide treatments), the increase in numbers of pests resistant to pesticides, the reduction in crop rotations, the increase in crops grown in monoculture and reduced crop diversity, the lowering of FDA tolerances for insects and insect parts in foods, and the enforcement of more stringent cosmetic standards by fruit and vegetable processors and retailers, the increased use of aircraft application technology, the reduction in crop sanitation (including less attention to the destruction of infected fruit and crop residues), the reduction in tillage, with more crop residues left on the soil surface, the culturing of crops in climatic regions in which they are more susceptible to insect attack, and the use of herbicides that have been found to alter the physiology of crop plants, making them more vulnerable to insect attack (Pimentel et al., 1991). These factors will be explored further in the discussion of alternatives to pesticide use.

Estimated agricultural benefits/costs with a reduction in pesticide use

A reduction in US pesticide use would require improving the efficiency of pesticide application technology supported by alternatives for chemical pest control. Such changes in some cases increase and in other cases decrease control costs. The costs and benefits of alternative controls are examined below.

Crop losses to pests

Losses from pests for 40 major crops grown with pesticide treatments were estimated by examining data on current crop losses, by reviewing loss data based on experimental field tests, and by consulting pest control specialists. Combining these data, however, was often difficult. For example, published data based on experimental field tests usually emphasize the benefits of pesticide use, thus loss data associated with pesticide treatments usually emphasize benefits over costs (Pimentel et al., 1978).

Moreover, field tests often exaggerate total crop losses since the assessments of insect, disease, and weed losses are carried out separately and then combined. For example, on untreated apples, insects were reported to cause a 50–100% crop loss, disease 50–60%, and weeds 6% (Ahrens and Cramer, 1985; Pimentel et al., 1991). This approach yields an estimated total loss of about 140% from all pests combined! A more accurate estimate of losses in the absence of pesticides ranges from 80% to 90% based on current cosmetic standards (Ahrens and Cramer, 1985). Exactly how much overlap exists among insect, disease, and weed loss figures for apples and for other crops is not known.

Our analysis has other important limitations. The figures for current crop losses to pests, despite pesticide use, are based primarily on USDA data and other estimates obtained from specialists. We emphasize that these data are estimates. For certain crops, little or no experimental data are available concerning different yields with and without pesticide use and various alternative control measures. In addition, in some cases, recent data were not available, so for these crops, our estimates were usually extrapolated from data on closely related crops.

Although we recognize the limitations of the data used in this analysis, we believe that there is a need to assemble all available information, in order to provide a first approximation of the potential for reducing pesticide use by one-half without any major sacrifices in yields. We hope that better data will be available in the future, so that a more complete analysis of pesticide costs and benefits can be made.

Reduction of the hazards associated with pesticide use is in itself a complicated issue, particularly because environmental and health-related trade-offs are often associated with changes in technology. Because of the complexity of these trade-offs, they could not be included in the analysis. One example, however, demonstrates the conflict of interest between reducing pesticide use and promoting soil conservation through the adoption of no-till practices or conservation tillage. Although no-till and conservation-till reduce soil erosion significantly (Van Doren et al., 1977), they also significantly increase the need for herbicides, insecticides, and fungicides (Taylor et al., 1984).

However, although reducing pesticide use may conflict with adoption of some no-till systems, highly cost-effective soil conservation alternatives to no-till do in fact exist. These include ridge-till, crop rotations, strip-cropping, contour planting, terracing, wind-breaks, mulches, cover crops and green-mulches (Moldenhauer and Hudson, 1988). Ridge-planting, which includes planting the crop on permanent ridges, 20 cm high along the contour, is growing rapidly in popularity as an effective replacement for no-till for most row crops. It is a form of conservation-till that has many advantages over no-till

(Forcella and Lindstrom, 1988). For example, ridge-till can be adopted without the use of herbicides, and it controls soil erosion more effectively than no-till (Russnogle and Smith, 1988).

Techniques to reduce pesticide use

The increase in crop losses due to pests associated with recent changes in agricultural practices suggests that some alternative strategies might be utilized to reduce pesticide use. Two important practices that apply to all agricultural crops, include widespread use of pest monitoring and the use of improved pesticide application equipment. Currently, many pesticide treatments are applied unnecessarily, and at improper times, due to a lack of programs which indicate when treatments are necessary. Furthermore, pesticides are lost unnecessarily during application (e.g. it is estimated that only 25–50% of the pesticide applied by aircraft actually reaches the target area (Akesson and Yates, 1984; Mazariegos, 1985)). By increasing pest monitoring and improving pesticide application equipment, more efficient pest control can be achieved. These effects are illustrated below by the detailed consideration of several crops.

Insecticides

Corn and cotton account for approximately 25% of the total insecticide use in agriculture in the US. Thus, reducing insecticide use in these two crops by substituting non-chemical alternatives would contribute significantly to a large reduction in overall insecticide use.

Corn. During the early 1940s, little or no insecticide was applied to corn, and losses to insect pests were only 3.5% (USDA, 1954). Since then, insecticide use on corn has grown more than 1000-fold while losses due to insects have increased to 12% (Ridgway, 1980). This increase in insecticide use and the 3.4-times increase in corn losses to insects are due primarily to reduction in crop rotations (Pimentel et al., 1991). Today, approximately 40% of US corn is grown continuously with 11 million kg of insecticide applied to this crop annually (Pimentel et al., 1991). By reinstituting crop rotations, large reductions in pesticide use could be achieved. Rotating corn with soybeans or a similar high-value crop generally increases yields and net profits (Helmers et al., 1986), although rotating corn with wheat or other low-value crops usually reduces net profits per hectare. From a more comprehensive perspective, however, the rotation of corn with other crops has several other advantages including reducing weed and plant disease losses as well as decreasing soil erosion and rapid water run-off problems (Helmers et al., 1986).

By combining crop rotations with the planting of corn varieties resistant to the corn borer and chinch bug, it would be possible to avoid 80% of the total insecticide used on corn whilst concurrently reducing insect losses (Schalk and Ratcliffe, 1977). Such a change is estimated to increase the cost of corn production by $10 per hectare compared with systems in which corn is grown continuously (Pimentel et al., 1991).

A new technique that controls rootworm by combining an attractant with insecticides has been reported to reduce insecticide requirements by 99% (Paul, 1989).

Cotton. The potential for reducing pesticide use in US agriculture is well illustrated by the changes in insecticide use that have occurred in Texas cotton production. Since 1966, insecticide use on Texas cotton has been reduced by nearly 90% (OTA, 1979). The technologies adopted to reduce insecticide use were: monitoring pest and natural enemy populations to determine when to use pesticides, biological pest control, host-plant resistance, stalk destruction (sanitation), adoption of a uniform planting date, water management, fertilizer management, use of rotations, clean seed, and changed tillage practices (OTA, 1979; King et al., 1986).

Currently, a total of 29 million kg of insecticide is applied to cotton, and we estimate that this amount could be reduced by approximately 40% through the use of readily available technologies (Pimentel et al., 1991). By using a monitoring program effectively, one could reduce insecticide use by approximately 20%. Through the use of pest-resistant cotton varieties and the alteration of planting dates, in most growing regions, insecticide use could be reduced by another 3% (Frans, 1985; Frisbie, 1985). An additional 10% reduction in insecticide use could be achieved through the replacement of the price support program with a free market and no price support program for cotton production (NAS, 1989). This change would allow cotton to be grown in regions with fewer insect pests, thereby reducing the need for insecticide use. However, the current price support program would have to change if society is to take advantage of these benefits. At present, however, this is a politically unattractive proposition.

Giving greater care to the type of application equipment employed, especially in reducing the use of ultra low volume application equipment on aircraft (which wastes 75% of pesticide applied), would increase the amount of insecticide reaching the target area. The amount of insecticide reaching the target area could be increased to 75% if ground-application equipment were used instead of aircraft application equipment (Mazariegos, 1985; Pimentel and Levitan, 1986). In addition, covering the spray boom with a plastic shroud can further decrease drift 85% (Ford, 1986), thereby allowing for an additional reduction in pesticide use.

Insecticide use on cotton might be reduced by another 6% through the implementation of other pest control techniques. These include cultivation of short-season cotton, fertilizer and water management, improved sanitation, crop rotations, the use of clean seed, and altered tillage practices (OTA, 1979; Grimes, 1985). Depending on the particular environment, insecticide use on cotton might be reduced by much more than 6%. For example, Shaunak et al. (1982) reported that insecticide use in the Lower Rio Grande Valley of Texas could be reduced 97% by planting short-season cotton under dryland conditions. This practice also resulted in a two-fold increase in net profits over conventional methods.

Thus, by implementing combinations of pest monitoring, improved application technology, short-season cotton, fertilizer and water management, improved sanitation, use of crop rotations, and tillage practices in cotton, insecticide use might be reduced by 40%. These alternative control measures should pay for themselves through direct reduced insecticide and application costs.

Herbicides

Corn and soybeans will be used to illustrate the potential for decreasing herbicide use considerably, because these crops account for about 70% of the total herbicide applied in agriculture (Pimentel and Levitan, 1986).

Corn. More than half (53%) of the herbicides used on crops are applied to corn (Pimentel and Levitan, 1986). More than 3 kg of herbicide are applied per hectare of corn, and more than 90% of the corn planted is treated. By avoiding total elimination of weeds herbicide use can often be reduced by up to 75% (Schweizer, 1989). At present, 91% of the total corn land is also cultivated to help control weeds (Duffy, 1992).

The average costs and returns per hectare from no-till and conventional-till crops have actually been found to be quite similar (Duffy and Hanthorn, 1984). For example, added labor, fuel and machinery costs for conventional-till practices for corn were approximately \$24 ha^{-1} higher than those for no-till. However, the costs for the extra fertilizers, pesticides, and seeds in the no-till system were \$22 ha^{-1} higher than in the conventional-till system (Duffy and Hanthorn, 1984).

It would be possible to reduce herbicide use on corn by up to 60% if the use of mechanical cultivation and rotations were increased (Forcella and Lindstrom, 1988). Corn and soybean rotations have been found to give substantially higher returns than either crop grown separately and continuously (Helmers et al., 1986). However, we assumed in our calculations that weed control costs might increase by approximately 30% because not all alternative practices and rotations are profitable.

Soybeans. The second largest amount of herbicides applied to any US crop are applied to soybeans, with approximately 96% of soybeans receiving herbicide treatment as well as some tillage and mechanical cultivation for weed control (Duffy, 1982). Several techniques have been developed that increase the efficiency of herbicide applications. The rope-wick applicator has been used in soybeans to reduce herbicide use about 90%, and the applicator was found to increase soybean yields 51% over those from conventional treatments (Dale, 1980). Moreover, a new model of recirculating sprayer saves 70–90% of the spray applied that is not trapped by the weeds (Matthews, 1985). Spot pesticide treatments are a third method of decreasing unnecessary pesticide applications.

Several alternative techniques are available to reduce the need for herbicide use on soybeans. These include ridge-till, tillage, mechanical cultivation, row spacing, planting date, use of tolerant varieties, crop rotations, spot pesticide treatments and reduced pesticide dosages (Tew et al., 1982; Helmers et al., 1986; Forcella and Lindstrom, 1988; Russnogle and Smith, 1988). Employing several of these alternative techniques in combination might reduce overall herbicide use in soybeans by approximately 60%. Despite the results of Tew et al. (1982) that indicate no added control costs for the alternatives, we estimated conservatively that the cost of weed control would increase by \$10 ha^{-1} (Pimentel et al., 1991).

Fungicides

When considering the possible reduction of fungicide use, apples and potatoes were selected as demonstration crops. These two crops account for 26% of all the fungicides used in US agriculture (Pimentel et al., 1991).

Apples. Most fungicides are applied to apples and other fruit crops (Pimentel and Levitan, 1986). Integrated pest management data for apples in New York State suggest that fungicide use on apples could be reduced by approximately 10% by improved monitoring and forecasting of disease based on weather data (Kovach and Tette, 1988).

In addition, a recent design in spray nozzle and application equipment demonstrated that the amount of fungicide applied for apple scab control could be reduced by 50% (Van der Scheer, 1984). Thus, by employing better weather forecasting and improved fungicide application technology combined with scouting, fungicide use on apples could be reduced by an estimated 20% (Pimentel et al., 1991).

Potatoes. Approximately 96% of potatoes in the US are treated with fungicides (Pimentel et al., 1991). Without fungicide treatments, losses from potato diseases ranged between 5 and 25%, while the losses with fungicide treatments were reported to be approximately 20% (Teng and Bissonnette, 1985). Shields et al. (1984) reported that the planting of short-season potatoes in Wisconsin reduced the number of fungicide applications by one-third. Correct storage, handling, and planting of seed tubers and proper management of soil moisture and fertility can minimize losses to most diseases (Rich, 1991).

Forecasting and monitoring might also be employed to reduce fungicide use between 15% and 25% (Royle and Shaw, 1988). Monitoring should concentrate on disease incidence and forecasting weather conditions, so that fungicides can be applied before an infection outbreak. Employing a combination of these control measures, it might be possible to reduce overall fungicide use on potatoes by approximately one-third at an estimated cost of \$5 ha^{-1} (Pimentel et al., 1991).

Overall pesticide reduction assessment

Substituting non-chemical alternatives for some of the pesticides used on 40 major crops, it is possible that total agricultural pesticide use could be reduced by approximately 50% (Pimentel et al., 1991). The added costs for implementing the alternative pest control measures are estimated to be approximately \$1 billion (Table 3). These alternatives would increase total pest control costs by approximately 25% and would increase total food production costs at the farm by 0.6%.

If alternative technologies that result in reduced crop yields were adopted the assessment of benefit and cost relationships would be quite different. For example, each 1% decrease in crop yield in agriculture results in a corresponding 4.5% increase in the farm price of goods. It is also important to note that crop overproduction is the prime reason that the US spends \$26 billion annually on price supports (Office of Management and Budget, 1989). Thus, if changes in pest control did in fact reduce yields, it might increase both farm income and decrease government subsidy expenses.

Environmental impacts

Society pays a high price for the use of pesticides. Pesticide-control technology costs approximately \$4.1 billion annually in the US, but this does not

Table 3

Current and potential reduced use of pesticides in US crops (million kg). Total pesticide costs (in dollars) plus total added alternative control costs (Pimentel et al., 1991)

	Current	Potential reduced	Total costs ($\$\times10^6$)	Added alternative control costs ($\$\times10^6$)
Insecticides	62.1	27.2	817.8	156.5
Herbicides	219.6	98.9	3115.8	845.3
Fungicides	37.6	26.6	207.4	16.5
Total	319.3	152.7	4141.0	1018.3

Table 4
Total estimated environmental and social costs from pesticides in the US

Public health impacts	\$787 million year^{-1}
Domestic animals deaths and contamination	\$30 million year^{-1}
Loss of natural enemies	\$520 million year^{-1}
Cost of pesticide resistance	\$1400 million year^{-1}
Honey-bee and pollination losses	\$320 million year^{-1}
Crop losses	\$942 million year^{-1}
Fishery losses	\$24 million year^{-1}
Bird losses	\$2100 million year^{-1}
Groundwater contamination	\$1800 million year^{-1}
Government regulations to prevent damage	\$200 million year^{-1}
Total	\$8123 million year^{-1}

include the environmental and public health costs. A recent study estimates that the environmental and public health costs of using pesticides cost the nation about $8 billion each year (Table 4).

Conclusion

Pesticides cause serious public health problems and considerable damage to agricultural and natural ecosystems. A conservative estimate suggests that the environmental and social costs of pesticide use in the US are at least $2.2 billion (Pimentel and Levitan, 1986) (Table 1) plus $1.2 billion for monitoring well and groundwater resources) annually, and the actual cost is probably double this amount. In addition to these costs, the nation spends $4.1 billion annually to treat crops with 320 million kg of pesticides.

This study confirms that it should be possible to reduce pesticide use by 50% at a cost of approximately $1 billion. Such a conclusion supports the projections of the OTA (1979) and the NAS (1989) as well as the policies adopted by the Danish and Swedish governments to legislate that pesticide use should be reduced by 50%.

The 50% US pesticide use reduction in our current assessment would help to satisfy the concerns of the majority of the public, who worry about pesticide levels in their food as well as about damage to the environment (Sachs et al., 1987). If pesticide use were reduced by one-half without any decline in crop yield, the total price increase in purchased food is calculated to be only 0.6% and is due to the increased costs of alternative controls. If assured that pesticide residues in food and the environment were greatly reduced, it seems likely that the public would be willing to pay this slight increase in food costs.

In addition, it is clear that the public would accept some reduction in cosmetic standards of food items if it would result in a concurrent reduction in pesticide contamination of food (Healy, 1989). This is confirmed by the growing popularity of organic food stores and supermarkets that guarantee pesticide-free foods (Hammit, 1986; Poe, 1988). Furthermore, the presence of parts of soft-bodied insects in highly processed foods, such as catsup and applesauce, carries no risk to public health and may even be of some nutritional value (Pimentel et al., 1977). The adoption of higher cosmetic standards has resulted in greater quantities of pesticides being applied to food crops. This rapidly growing use of pesticides for cosmetic purposes is detrimental to both public health and the environment, and it is also contrary to public demand (Pimentel et al., 1977).

Although some of the data used in this preliminary investigation have obvious limitations, the estimates presented suggest that it should be possible to reduce pesticide use in the US by up to one-half. It is hoped that more complete data on this issue will be assembled and more detailed analyses made concerning the potential for reducing pesticide use. In particular, more data are needed on identifying those agricultural technologies that have contributed to the increase in pesticide use during the past 40 years whilst simultaneously increasing crop losses to pests.

Implementing a national program to reduce pesticide use in agriculture will require the combined education of farmers and the public and some new regulations. In addition, it will require that the federal government revise its current policies, such as its commodity and price support program, that discourage farmers from employing crop rotations and other sound agricultural practices (NAS, 1989). Several current government policies actually increase the incidence of pest problems and pesticide use (NAS, 1989). At the same time, a greater investment is needed in research on alternative pest control practices. Many opportunities exist to reduce pesticides through the implementation of new environmental, cultural, and biological pest controls (Pimentel, 1991). We strongly support the NAS research recommendations for a search for alternative pest controls (NAS, 1989).

The public seems to be concerned about pesticides contaminating their food and environment, so they must decide to accept the small economic costs necessary to reduce pesticide use. It is hoped that the public, state and federal governments will investigate the ecology, economics, and ethics of pesticide reduction in agriculture. The present analysis suggests that it is essential that a careful assessment be made to evaluate the benefits and risks of pesticides and non-chemical alternatives for society.

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